LCA Case Studies

Evaluating the Environmental Performance of Passenger Vehicles *

Extended Abstract

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Intention, Goal, and Scope. An indicator or metric is proposed to reflect the environmental and resource impacts of passenger vehicles. Primarily intended to assist consumers in purchasing decisions, the metric is designed to provide timely, relevant and meaningful information that captures most of the environmental impacts occurring throughout the vehicle life cycle. The paper presents the criteria for such metrics, reviews the relevant literature, demonstrates the metric for the model/year 2000 vehicles, and discusses the use, evolution and limitations of the indicator.

Background. Vehicles are significant emitters of air pollutants and a major influence on the environment. The life cycle of a vehicle results in many environmental and resource impacts, some of which can be difficult and/or controversial to evaluate. While several eco-indicators have been developed, a need exists for comprehensive, objective and comparative information to describe the environmental impacts of vehicles on a brand/model basis. Such information can increase the consumer awareness of a vehicle's environmental performance, as well as the automobile manufacturer's corporate governance, product planning and marketing practices.

Methods. Environmental performance criteria for vehicles are developed using principles of life cycle assessment (LCA), methods used to define eco-indicators, and available or reasonably obtainable and quality-assured data. Previous LCA studies are reviewed to help formulate the suggested metric. These studies are consistent in showing that the vehicle use phase (including fuel production) currently accounts for most emissions of greenhouse gases as well as most of the conventional pollutants.

In the suggested metric, estimates of in-use emissions are combined using a weighting based on LCA results and an estimate of the severity of impacts. Emissions of the four regulated and conventional pollutants are given half of the total score and each receives equal weight. This approximates the population in regions not in compliance with US air quality standards, i.e., emissions of ozone-forming pollutants nitrogen oxides (NO_x) and non-methane hydrocarbons (NMHC) together represent 25% of the score, and emissions of toxicants carbon monoxide (CO) and particulate matter (PM) each represent 12.5%. Recognizing the potential magnitude and consequence (but also great uncertainties) of impacts related to energy consumption and greenhouse gas (GHG) emissions, carbon dioxide (CO_2) and other GHG emissions receive a larger weighting, 40% of the total. The pollutant and energy efficiency scores, which are proportional to the reduction in emissions from a baseline year 2000 vehicle, are based on emission certifications, and highway and city fuel economy estimates. In addition, the vehicle-related solid waste generation and resource consumption, which is based on the percent recycled content in the vehicle, is given the final 10% of the score. At present, the recycled content of vehicles is not available on a brand/model basis, however, this information is not difficult to determine. Scores for advanced technology vehicles, e.g., electric vehicles, are derived in a manner consistent with conventional gasoline and diesel-powered vehicles.

The relative ranking or weighting of emissions can be based on many factors, and the uncertainty and ultimately the subjectivity of any weighting system is recognized and discussed at length. Nonetheless, the suggested indicator incorporates meaningful measures of environmental impacts. Further, it is clearly definable, consistent, verifiable, transparent and understandable to vehicle purchasers and other stakeholders. For these and other reasons discussed in the paper, the indicator can provide valuable information for both purchasing decisions and improvement analyses.

Results. The 200 brand/models and 1,450 engine/drive train configurations in the 2000 model year demonstrate a large range of emissions, e.g., greenhouse gas emission estimates range from 176 to 1187 g/mile in CO_2 equivalents, while

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NO_x, NMHC, CO, and PM range from 1.1, 0.73, 5.0, and 0.08 g/mile, respectively, to 0.0 g/mile. (The NMHC estimates include running and evaporative emissions.) The air pollution scores increase rapidly (scoring 65 to 75 points of 100 possible) as vehicle efficiency reaches 25 to 35 mpg and vehicle certification achieves LEV and ULEV (low and ultra-low-emission vehicle) standards. Scores increase only incrementally afterwards, since most emissions have been eliminated or reduced. The highest scores (85 to 90 points) are achieved by high efficiency (>50 mpg) zero-emission-vehicles with very low emissions throughout the fuel cycle. Note that this analysis excludes the solid waste and material consumption score (which can contribute a maximum of 10 points). The scores allow consumers to compare vehicles within a vehicle class, e.g., subcompacts, as well as between classes, e.g., full-size cars and minivans. They also demonstrate trade-offs between vehicle efficiency and emission standards, information that vehicle manufacturers can use to achieve desired environmental performance targets. Uncertainties and data issues in the suggested indicator include the following: alternative weightings of environmental burdens, e.g., using chemical potency, risk and social costs; reliability of emission certifications and unanticipated deterioration of emission controls; upstream emissions, e.g., in manufacturing, which may grow in importance as vehicle emissions are reduced; current lack of recycling data that is specific to brand/models; and issues related to vehicle lifetime and functional comparability.

Conclusions. The metric emphasizes environmental burdens in the use stage, which LCA studies indicate account for majority of emissions in the vehicle life cycle. While subject to limitations arising largely from information gaps, the suggested metric provides a consistent and comprehensive indicator of environmental performance useful in comparing the environmental performance of currently available vehicles and guiding consumer purchasing decisions.

Future Prospects. No single metric can capture the diversity of all possible impacts, concerns and trade-offs resulting from vehicles or other complex systems. Because the weighting of the component measures is judgmental and based on incomplete information (see below), results are considered as a first step in a comparative rating system, and the metric should be updated as additional information becomes available. Nevertheless, the suggested metric is believed to provide a useful and objective indicator of the life cycle impact of vehicles.

Keywords: Air pollutants; automobiles; emissions; environmental indicators; green labeling; greenhouse gas; indicators; life cycle assessment; motor vehicles; pollution; recycling; vehicles

Review and Criticisms. This paper has been through a long and extensive review process in which the authors and referees on this paper have discussed many technical and policy aspects of this paper. Most interest (and controversy) focus on the following two points:

1. This paper does not describe an LCA; and
2. The weighting system used to combine emissions and other impacts is subjective.

Regarding the **first point**, it should be clear to readers that we have not performed an LCA for a vehicle. The primary purpose of his paper is to develop a practical indicator or metric that summarizes environmental performance in an objective, consistent, transparent and meaningful manner so as to guide consumer-purchasing decisions. However, we do review much of the LCA literature regarding vehicles, which is consistent in showing that the LCAs performed for vehicles have obtained similar results in that in-use emissions dominate all other aspects of the vehicle life cycle. (This is dramatically shown in Fig. 1 of the paper). While we do not discount 'upstream' or 'downstream' emissions, these are small relative to the operating emissions (which include the fuel cycle). Moreover, current inventories do not allow these emissions to be apportioned on a brand/model basis. Primarily for the former reason, however, the suggested metric utilizes in-use emissions to derive scores for greenhouse gases and the conventional pollutants. As suggested in the paper, as additional and high quality information becomes available, it should be incorporated into the metric.

The second point regarding the subjectivity of the indicator is interesting and significant. One of the referees has argued that the weighting cannot be justified on the basis of health effects or any other basis, for that matter. It is then concluded that the index is largely subjective and arbitrary, and by extension, of limited value. For many reasons, most of which are presented in the paper's discussion, we disagree with both the initial statement and the stated ramifications. The paper clearly states no single metric can capture the diversity of all possible impacts, that any single metric by necessity reduces information and represents a simplification that to varying degrees will have judgmental elements, that many approaches might be used to develop weights, and that the uncertainty is high in most of these approaches. Nonetheless, the thesis of this paper is that for many purchasers, a scalar metric will provide useful, valuable and relevant information. We should not – and cannot justifiably – wait until scientific consensus is achieved regarding the valuation of the disparate impacts to provide consumers with information. Moreover, as discussed below, the weightings may not even matter very much in the rankings of environmental performance.

The paper discusses the weighting used and its shortcomings. We do not think that the weighting is arbitrary; but

it is simplified, based on the available and limited information available, and clearly a degree of judgment is involved. For conventional pollutants, our justification includes (1) transparency, in that conventional pollutants are weighted equally; and (2) health-related, in that the equal weighting approximately represents populations exposed to unacceptable levels of these pollutants. For greenhouse gas emissions, we (and we believe most others) would agree that estimates of the long term impacts posed by greenhouse gases emissions (and to some extent by waste issues) are highly uncertain, yet highly significant and at least as important as problems posed by ozone, particulate matter, etc. So we opted for a fairly high weight for greenhouse gases – nearly equivalent to the sum of the weight given to the conventional pollutants. Actually, the weighting among the conventional pollutants is less important since all of these pollutants tend to be reduced with the more stringent certifications, i.e., a SULEV has lower emissions of CO, NO_x, and NMHC than a LEV or Tier I vehicle. In any event, for these and other reasons, the proposed weights are considered preliminary; to be superceded when additional data allow the metric to become both more comprehensive and more impact-based.

Another and substantive argument against the index is that it is incomplete. The index is based on scores for energy efficiency (derived from greenhouse gas emissions), emissions of conventional pollutants, and vehicle waste generation and resource consumption. From a scientific standpoint, the index transcends the narrow focus of governmental agencies (energy, environment, etc.) that tend to deal in a piece-meal fashion with vehicle-related impacts. Still, the index presently does not incorporate impacts from upstream discharges, e.g., manufacturing, fuel refining, drilling and mining wastes, brines, etc., and some operating and downstream impacts, e.g., spills of MTBE, acidification, toxicity, etc. Unfortunately, the available data and methodologies do not support an inventory, allocation and impact evaluation method that can provide quality-assured estimates of these impacts. To an extent, this issue is offset by the dominance of in-use emissions and the fact that vehicles use identical or similar commodities in their manufacture, maintenance and disposal.

Our **key points** in this discussion are: (1) decisions by consumers and manufacturers can benefit from a reasonably formulated and quality-assured indicator, despite its limitations (and all indicators are imperfect); (2) LCA concepts provide an appropriate basis for such indicators, which are expected to evolve with new information; and (3) the 'paralysis by analysis' syndrome should not prevent the formulation and application of indicators given the immediate application and, to us, their increasing need.

Author Final Responses. The referees have raised important issues that we have carefully considered in both the formulation and the suggested application of the indicator. It is important to note that the indicator is intended for a specific purpose, namely, as a guide for consumer purchasing decisions. Important goals for this application includes objectivity, comprehensiveness, accuracy, quality assurance, etc., as well as timeliness, transparency, and specification on a brand/model basis, the way consumers purchase vehicles. Consumers – and the environment – would benefit with an improved rating scheme. Clearly, there is room for scientific debate regarding the weighting system. It is arguable that any weighting scheme is ultimately uncertain and subjective, built on the preferences and judgments of the scientists involved, the data available, and the incomplete knowledge of the time. Furthermore, the sensitivity to the weighting isn't likely to be large, so the practical implication of whether CO_2 emissions should receive 40%, 39% or 48% of the weight, for example, is likely to be small.

We do favor completion of LCAs for vehicles that give detailed information regarding specific environmental burdens and impacts at each life cycle stage, following the intent of the ISO 14000 series. More complete information is needed to guide improvement analyses, to set national research and regulatory priories, and other purposes. But simpler and higher level, i.e., comprehensive, indices are also needed. These do not obscure or displace the detailed LCA analysis, in fact, they should be based on them. They simply serve a different purpose. With appropriate linkages, consumers can always obtain the detailed basis for the composite indicator, and, if desired, weight environmental impacts differently, as they clearly do with other vehicle attributes.

We appreciate the Journal's receptiveness to host this debate. The approach used to formulate environmental indicators, as well as their validation and application, warrants additional scholarship. There remain many important technical issues to resolve, some of which have been the focus of the referees' comments. Additionally, there are important policy, educational, and behavioral issues regarding, for example, the use, availability, and sponsorship of environmental indicators in the market. We (and the editors) invite comments from readers of the Journal and look forward to a lively debate on this topic.